

HORIZONTAL COLLECTORS: DESIGN PARAMETERS, MATHEMATICAL MODEL, AND CASE STUDY

Gregory P. McCarron, PE
SCS Engineers
W. Nyack, New York

Darrin D. Dillah, PhD, PE
SCS Engineers
Reston, Virginia

Owen R. Esterly, PE
Chester County Solid Waste Authority
Honey Brook, Pennsylvania

ABSTRACT

Horizontal collectors have been used successfully at many landfills to collect landfill gas (LFG) and are an acceptable method for collecting LFG under the New Source Performance Standards (NSPS) for municipal solid waste (MSW) landfills. Our literature review indicates that the Los Angeles County Sanitation District uses horizontal collectors extensively at its many landfills and first reported on their use in 1982. However, there is a dearth of published design criteria, design details, and performance data related to horizontal collectors that consider all of the critical system parameters. Most of the publications present limited empirical data and anecdotal observations. This paper is intended to advance the industry by providing the design engineer with a theoretical basis for establishing the key system parameters. It presents recommended design criteria, a mathematical model, and a case study.

Our mathematical model provides an understanding of radius of influence and its impacts due to other system parameters such as waste permeability, flow rate, and applied vacuum. Combining the theoretical basis with actual test data, the design engineer can develop a practical and cost-effective design for any particular landfill.

The case study summarizes our evaluation of a horizontal collector recently installed at a Pennsylvania MSW landfill. Using field data for model calibration, we established parameters such as required well head vacuum, maximum horizontal collector length, and collector spacing.

INTRODUCTION

For over 20 years, horizontal LFG collectors have been successfully employed at numerous landfills across the country. The Los Angeles County Sanitation District (LACSD) uses horizontal collectors extensively at its

many landfills and first reported on their use in 1982. Horizontal collectors are being used more often at active landfills, as they are required or need to collect LFG from their active cells. The major advantages of horizontal collectors versus vertical wells are their compatibility with active landfill operations and their relative ease of installation.

Dated back to the inception of the NSPS, the EPA notes that horizontal collectors are an acceptable method for collecting LFG. Moreover, the NSPS Enabling Document includes case studies that discuss horizontal collector design (refer to Appendix E of the Enabling Document). One case study regarding the Scholl Canyon Landfill in California notes that the horizontal collectors ranged in length from 1300 feet to 1800 feet with a horizontal spacing of 250 feet. The trench dimensions were 2 feet, 3 inches wide by 5 feet, 9 inches deep. The collectors included alternating sections of 15-inch and 18-inch diameter pipe. Flows in each collector varied in the range of 200 to 300 cubic feet per minute (cfm) with an average vacuum of less than 1 inch of water column (in-w.c.).

In a 1982 presentation, LACSD presented design and operational information for the Puente Hills Landfill. Initial testing was performed on an 850-foot long horizontal collector. The collector trench was 4 feet wide by 5 feet deep and included alternating sections of 6-inch and 8-inch diameter polyvinyl chloride (PVC) pipe. The collector included 200 feet of solid pipe. At a flow of 450 cfm, the measured horizontal radius of influence was 150 feet. As such, additional collectors were designed at 300 feet spacing horizontally and 80 feet vertically.

Reporting on the Cedar Hills Landfill in Washington, designers used a 2-foot by 3-foot trench and 6-inch diameter pipe. The spacing of the trenches was 200 feet horizontally and 45 feet vertically. The longest collector

was 600 feet but as many as four collectors were controlled by the same control valve.

Reporting on the Albany Landfill in New York, designers evaluated three different designs: alternating 6-inch and 10-inch diameter pipe, 4-inch pipe, and 4-inch pipe inside larger culvert pipe sections. The spacing of the trenches was 100 feet horizontally and 30 feet vertically.

As can be seen from these examples, design criteria for horizontal collectors vary widely from site to site. In this paper, a mathematical model is developed for horizontal collectors that is useful for establishing suitable system design and/or operational parameters (e.g., flow rate, pressure, and spacing). The paper also presents a case study, data from which is used to verify the model, and summarizes recommended design criteria.

MATHEMATICAL MODEL

SCS developed a simple mathematical model to describe the flow dynamics around a horizontal collector. Depending on the objective, the model can be used to estimate the pressure distribution around a collector, radius of influence, permeability, or other parameters. It is derived from Darcy's equation and the following assumptions:

- Laminar, radial flow towards the collector.
- Negligible elevation and velocity heads, and gas compressibility.
- Waste is homogeneous and isotropic.

In essence, the model assumes that the flow paths are radial and that isobars (lines of equal pressure) form concentric cylinders around the collector.

Our mathematical model is as follows:

$$\psi_1 - \psi_2 = \frac{Q}{CR_f^2 LK} \left(R_f^2 \ln \frac{r_2}{r_1} - \frac{r_2^2}{2} + \frac{r_1^2}{2} \right), r_2 > r_1 \quad \text{Eq. (1)}$$

where

ψ	=	Vacuum,
r	=	Radial distance measured from the center line of collector,
Q	=	Flow rate,
C	=	Unit conversion constant,
R_f	=	Radius of influence,
L	=	Length of perforated pipe, and
K	=	Waste permeability.

CASE STUDY

Background

The Chester County Solid Waste Authority (CCSWA) operates the Lanchester Landfill, an active municipal solid waste landfill located on the border of Chester County and Lancaster County in Pennsylvania. The facility accepts municipal solid waste and permitted residual wastes for landfill disposal. The landfill complex includes a number of solid waste disposal areas including: IU (8 acres), Mountain Top (9 acres), and Areas A (76 acres), B (37 acres), and C (48 acres). All areas are closed to further waste disposal, except Area C, which is the active fill area. A future Area D is planned as well. Refer to Exhibit 1.

Landfilling in Area C began in April 1997. Area C includes a composite secondary liner and a geomembrane primary liner. Total airspace is approximately 4.2 million cubic yards and the projected life is until early 2007. CCSWA has installed a leachate recirculation system in Area C and began recirculating leachate in 2001. In 2000, CCSWA installed two horizontal gas collectors in Area C (see Exhibit 2).

Test Layout

Six multi-depth monitoring probes were installed at 90-degrees to the east end of the northern collector as shown in Exhibit 2. The probes were installed at the following distances from the collector:

- Probe Cluster P-1: 3.5 feet.
- Probe Cluster P-2: 17.3 feet.
- Probe Cluster P-3: 39.3 feet.
- Probe Cluster P-4: 1 foot.
- Probe Cluster P-5: 15 feet.
- Probe Cluster P-6: 45 feet.
- Probe Cluster P-7: 2.3 feet.

At each probe cluster, one probe was installed at the same elevation as the horizontal collector while a second probe was installed 10 feet higher (except at P-7).

Probe P-7 was located about 600 feet from the west end of the collector at an offset of 1 foot. This probe was used in our analysis to help evaluate the distribution of vacuum within the horizontal collector trench itself.

Exhibit 3 presents the typical monitoring probe cluster detail. Six inches of gravel pack were placed, and then 1-inch schedule 40 PVC with a 1-foot screen was placed in the borehole. An additional 1.5 feet of gravel pack was placed, then general fill soil and a two-foot bentonite seal. General fill brought the borehole up to the 10-foot depth and the monitoring probe configuration was repeated. Each monitoring probe was equipped with a quick connect fitting for pressure monitoring.

A monitoring port was also installed on the aboveground header to allow for flow measurements with a pitot tube. Refer to Exhibit 2.

Test Procedures

A three-day test of the horizontal collector system was undertaken on July 17 through 19, 2001. The test proceeded as follows:

- On day one, vacuum was kept at the historical setting at the east end of the northern collector (approximately 5.8 in-w.c.) and at the west end.
- Data was collected and recorded every hour (9 a.m. to 3 p.m.), on each day, as follows:
 - Pressure at all monitoring probes, both wellheads, and the flow monitoring port.
 - Methane, oxygen, carbon dioxide, balance gas and temperature at the east and west wellheads, and the flow monitoring port.
 - Flows at the east end of the Area C Landfill and at both wellheads.
- At the end of day one, the vacuum was adjusted at the east end to a higher setting (approximately 7.3 in-w.c.).
- At the end of day two, the vacuum was adjusted at the east end to a lower setting (approximately 6.6 in-w.c.).

Data Discussion

Pertinent data collected during the three-day test program included flow rate as measured at the flow monitoring port with a pitot tube, well head pressure, and probe pressures.

General comments regarding the data are as follows:

- The deep and shallow probe vacuums decrease the further the probe is from the collector.
- The deep probe vacuums at location 2 (i.e., probes 4, 5, and 6) were less than that at location 1 (i.e., probes 1, 2, and 3), which is expected since location 2 is further away from the vacuum source. The one exception was Probe 4, which was explained upon review of the probe construction notes: Probe 1 was actually drilled 3.25 feet away from the collector while Probe 4

was drilled at distance of 1 foot from the collector.

- The shallow probe vacuums were greater than the deep probe pressures at location 2. This was not expected as it suggests that the vertical permeability (and "radius" of influence) is greater than the horizontal permeability. We suspect that the shallow probes were affected by barometric pressure. Our experience is that a changing barometer can affect the upper reaches of the landfill and cause negative or positive pressures with a rising or falling barometer, respectively. We did not further analyze the shallow probes based on this barometric interference.
- Flow from the collector correlated with the vacuum applied; i.e., the flow increased when the vacuum increased.
- The methane content of the collected LFG suggests that minimal air intrusion was occurring during all three test days. The depth of waste over the collector is about 16 to 17 feet, which suggests that the vertical radius of influence is less than 16 feet.
- The deep probe at P-6 (45 feet away from the collector) was slightly positive on July 17 and July 19 when the average vacuum applied was 5.8 in-w.c. and 6.6 in-w.c., respectively. This probe was slightly negative on July 18 when the applied vacuum was 7.3 in-w.c. This suggests that the horizontal radius of influence was about 45 feet when the applied vacuum was about 7 in-w.c.
- The probe at P-7 was at positive pressure during the majority of the test. Probe P-7 is about 500 feet east of the west well head and about 1,000 feet west of the east well head. The probe was zero pressure when the applied vacuum was about 7 in-w.c. at both the east and west well heads.
- The flow rate measured at the flow monitoring port was higher than expected (ranging from 300 to 360 scfm). The limited extent of LFG collection facilities in the area may partly explain this. LFG may be entering the zone of influence of the horizontal collector due to positive LFG pressure. Once a more comprehensive system is installed, we would expect that the flow from a typical horizontal collector would be less than 300 scfm.

Modeling Results

For this test, the known/measured parameters in Eq. (1) are probe vacuums (ψ), probe distances from collector (r), and flow rate (Q). The unknown parameters are R_f , L , and K . We developed a computer program to evaluate these three unknown parameters using a best-fit analysis; i.e., values are selected such that the sum of the square of errors between the actual data and the model output are minimized.

For example, we first considered the data collected for the deep probes at location 2 (P-4, P-5, and P-6), on July 18, 2001. Average flow was 360 standard cubic feet per minute (scfm), and average vacuum at P-4, 5, and 6 were 0.74, 0.17, and 0.02 in-w.c., respectively. We estimate that probe distances from the collector are about 1 foot, 15 feet, and 45 feet, respectively. Using this data, the computer program evaluates the difference between actual and calculated probe vacuums (i.e., error) for a selected R_f , L , and K combination, and repeats this error calculation for a series of R_f , L , and K combinations. The R_f , L , and K combination that produces the least error is selected as the best fit. For the test data, the best-fit combination is R_f of 50 feet, L of 370 feet, and K of $1.53E-4$ feet/sec. Exhibit 4 shows the results graphically, and indicates an almost perfect fit of the data.

The same approach was applied to the data collected at locations 1 and 2 for all three days at the deep probes. Exhibit 5 shows the results for location 1 on July 18, and similarly indicates a close fit of the data. The best fit combination is R_f of 52 feet, L of 440 feet, and K of $1.53E-4$ feet/sec.

In summary, our modeling indicates that R_f is approximately 50 feet and L is on the order of about 400 feet, based on the July 18 flow and vacuum conditions.

Practical Considerations

Our model assumes that the zone of influence of the horizontal collector is a cylinder shape, with a radius of R_f and a length of L . However, based on the test data and our experience, we estimate that the cross section is more of an elliptic shape as opposed to a circular shape (i.e., the vertical "radius" is less than the horizontal "radius"). Also, we expect that the elliptic shape tapers as the distance from the vacuum source increases. The end result is a zone of influence that is analogous to a "squashed cone" as opposed to a perfect cylinder.

This suggests that our modeling results may underestimate L , the length of the zone of influence, while overestimating R_f in the vertical dimension. Considering the empirical test data and the width of the landfill, we recommend that one wellhead be provided for every 600 feet of horizontal

collector. For example, for our case study landfill, we recommended a well head on both the east and west side of the horizontal collector. Two horizontal collectors should not be tied into one well head, unless the applied vacuum can be increased substantially or the collectors are very short.

To reduce the tapering effect or the cone shape, it is important to minimize the head loss within the horizontal collector pipe itself. Based on the test results and our experience, we recommend that 6-inch pipe be utilized to minimize head loss.

For our case study landfill, we recommended using a horizontal radius of influence of 50 feet, based on the test program and our analysis, which equates to spacing of 100 feet on-center for the horizontal collectors. The vertical radius of influence appears to be less than 16 feet. We recommended using a vertical radius of influence of 15 feet, which equates to a spacing of 30 feet vertically.

Examining Eq. [1], the important variables are applied vacuum, flow rate or gas generation, radius of influence, length, and permeability. As the applied vacuum increases, the radius of influence will increase, with everything else being equal. Based on the test results and other experience, the LFG blower and header system should be designed to provide a minimum of 10 in-w.c. vacuum to each well head to realize a horizontal radius of influence of 50 feet or more.

With installation of a comprehensive LFG collection system, we expect that the flow rate from a typical horizontal collector will be less than that measured during the test. With decreasing flow rate, the radius of influence will increase, with everything else being equal.

However, as the permeability decreases, the radius of influence will decrease. We expect that the permeability will decrease at a landfill as the waste decomposes and is loaded with additional waste. This process will be further accelerated at a landfill that recirculates leachate. The degree to which the permeability will decrease is dependent on several site-specific variables and is beyond the scope of this paper.

Additionally, it is possible that horizontal collectors can be flooded with leachate/condensate due to local perched conditions, preventing collection of LFG. The likelihood of water blockages increases when leachate recirculation is practiced. Hence, we note that horizontal collectors can effectively collect LFG initially, but with changing landfill conditions over time, their effectiveness may diminish. Vertical extraction wells may have to be installed at such a point in time.

DESIGN PARAMETERS

We recommend the following design parameters for a typical MSW landfill in the Northeast based on the model, the test program and our experience:

1. Space horizontal collectors at 100 feet horizontally and 30 feet vertically.
2. Use a minimum of 6-inch pipe within the typical horizontal collector. We suggest ADS pipe provided proper consideration is given to external pipe loads.
3. Make available 10 in-w.c. vacuum to each well head.
4. Provide a separate well head for every 600 feet of horizontal collector.
5. Provide 75 feet of solid pipe, measured from the outside side slope, prior to placement of the slotted pipe. If there is an air "short circuit", then the applied vacuum will be lost due to the large amount of air flow (i.e., high head loss), and vacuum will not reach the slotted sections further down the horizontal collector.
6. Locate the horizontal collectors away from leachate recirculation trenches to minimize water blockages.

REFERENCES

USEPA, 40 CFR 60 Subpart WWW.

USEPA, September 1998, "Summary of the Requirements for New Source Performance Standards and Emission Guidelines for Municipal Solid Waste Landfills", EPA-453R/96-004.

SCS Engineers, August 2001, "Test Report: Evaluation of Horizontal Landfill Gas Collection Trenches".

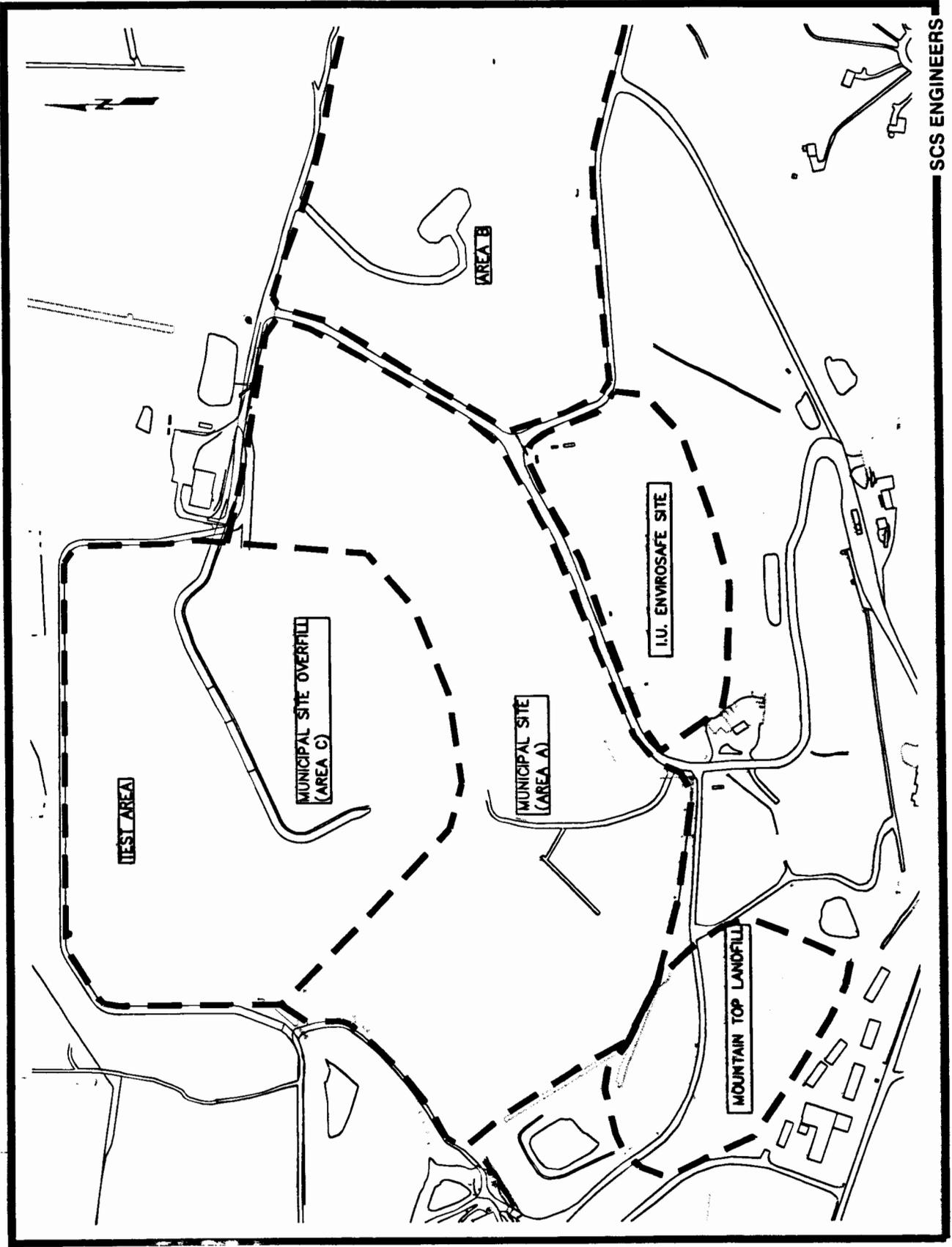


EXHIBIT 1. LANCHESTER LANDFILL

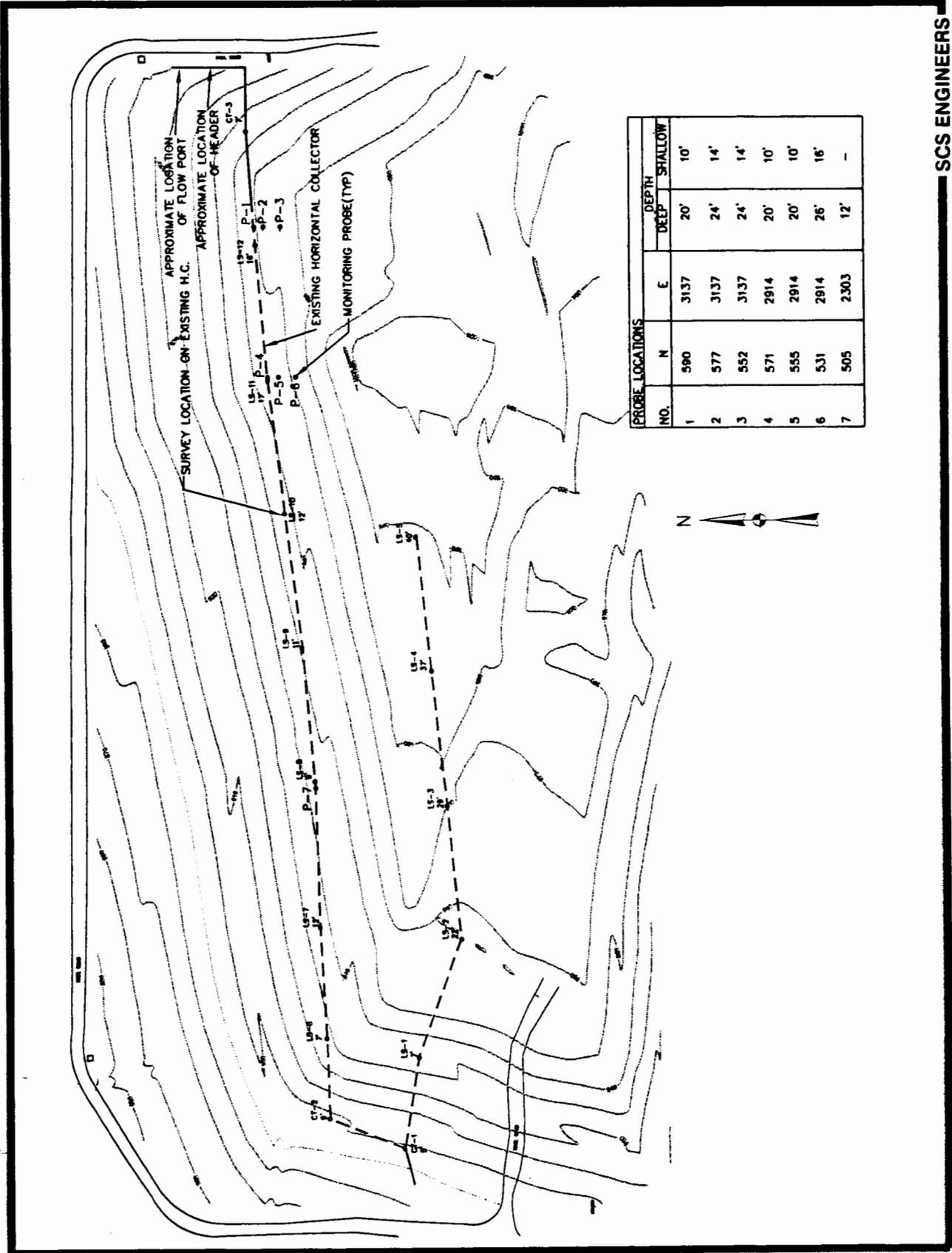


EXHIBIT 2. TEST FACILITY LAYOUT

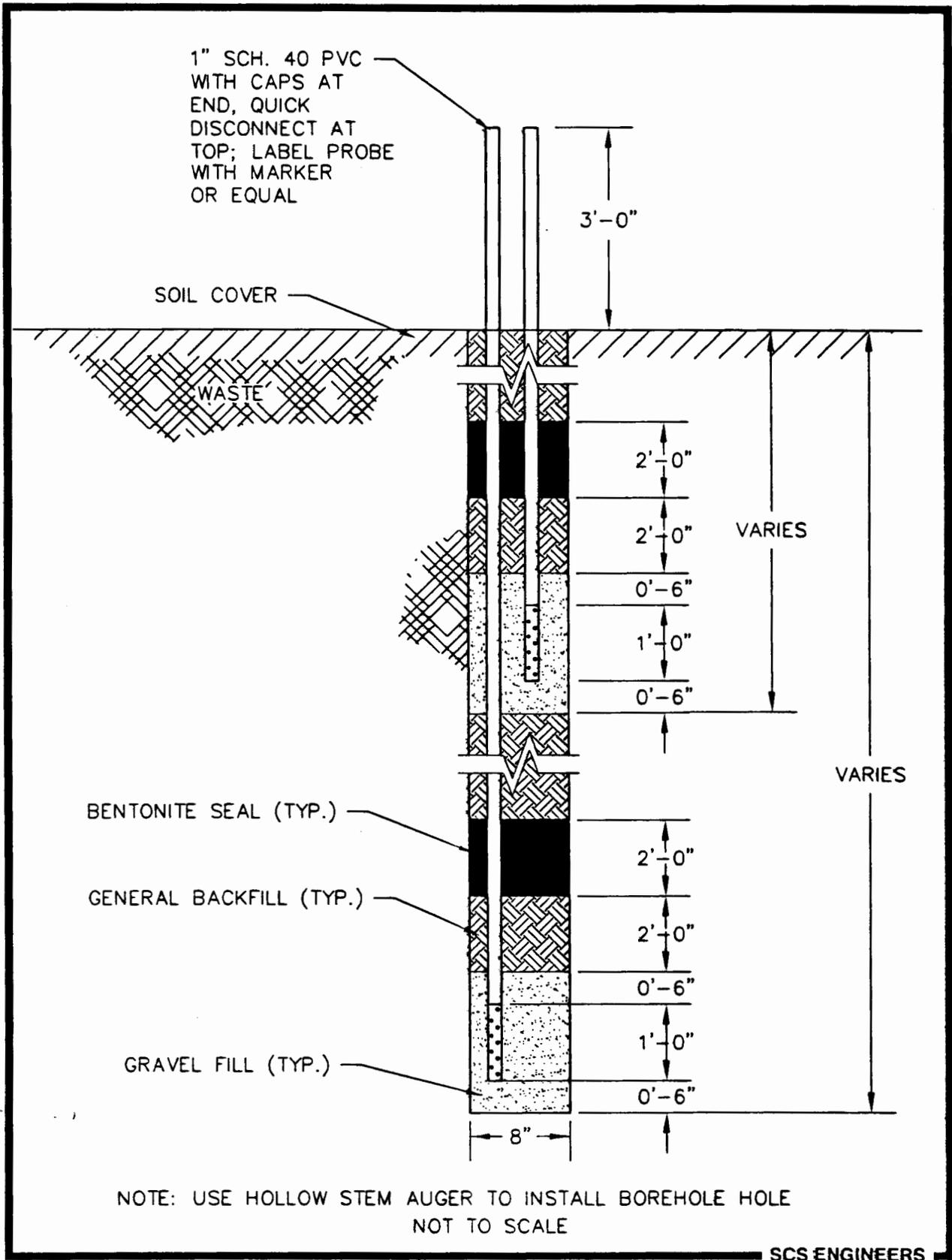


EXHIBIT 3. MONITORING PROBE DETAIL

EXHIBIT 4. Best Fit Curve for P4-P6, Deep Probes (7/18)

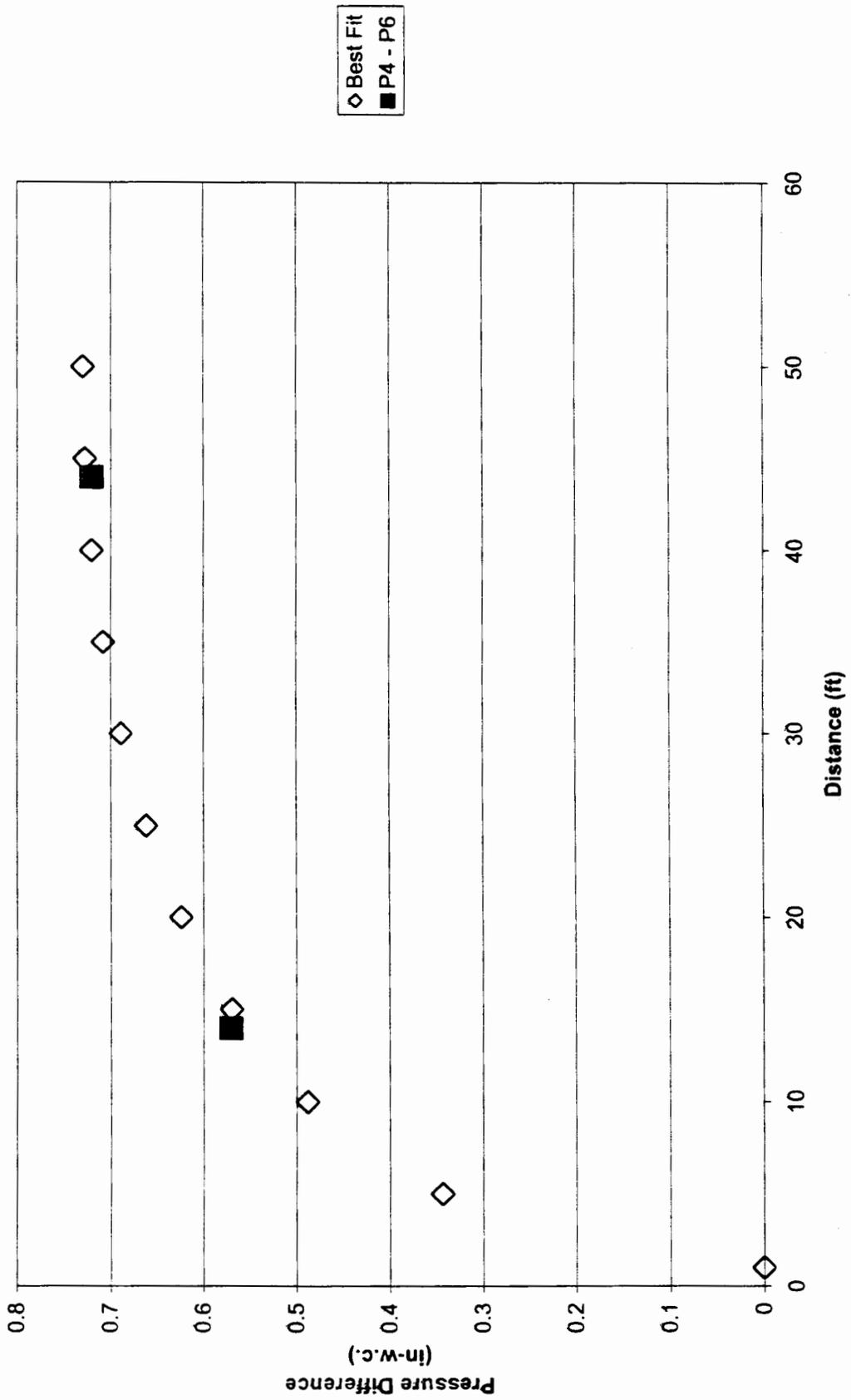
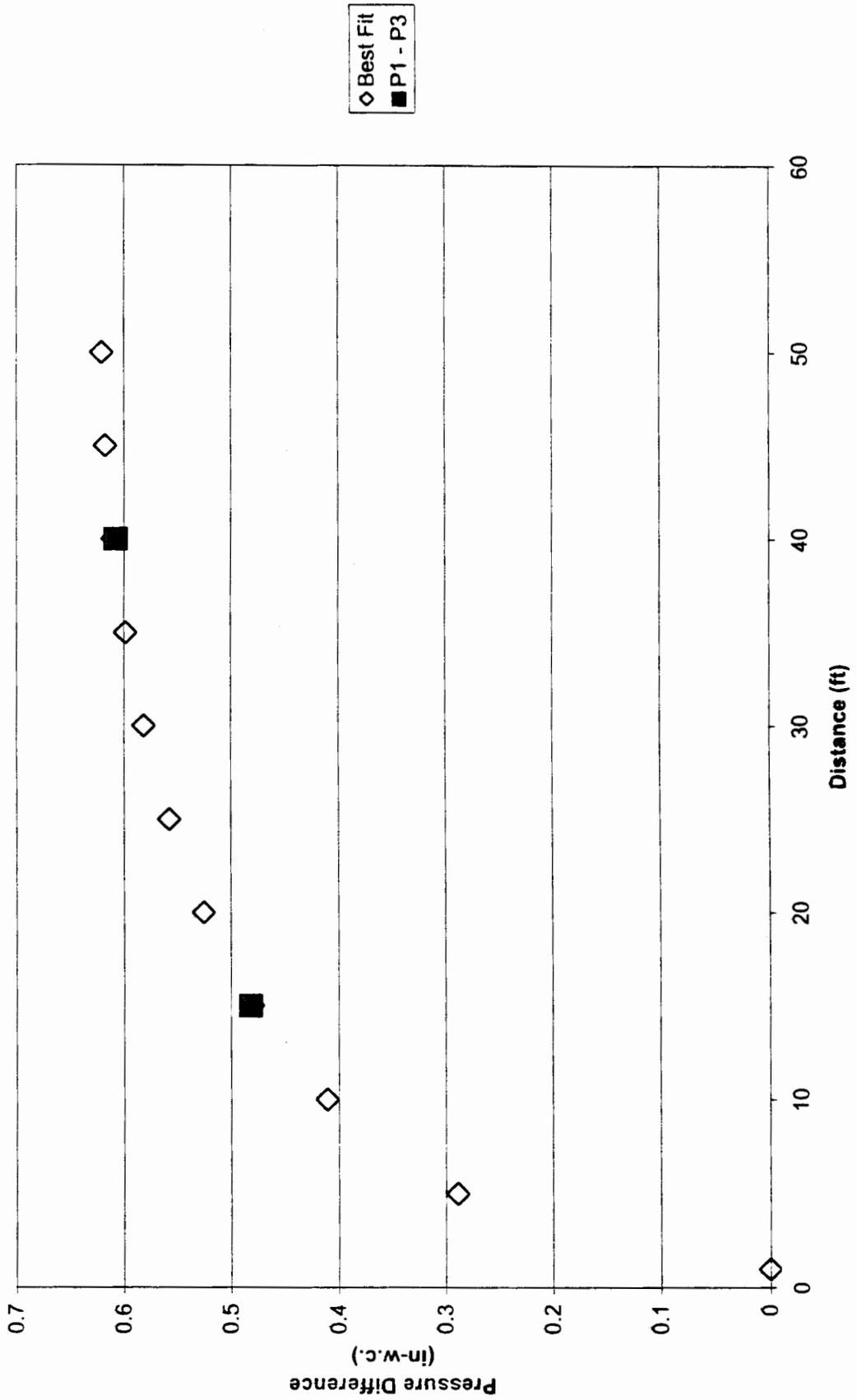


EXHIBIT 5. Best Fit Curve for P1-P3, Deep Probes (7/18)



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